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Shark conservation risks associated with the use of shark liver oil in SARS-CoV-2 vaccine development

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Abstract: The COVID-19 pandemic may create new demand for wildlife-generated products for human health, including a shark-derived ingredient used in some vaccines. Adjuvants are a vaccine component that increases efficacy, and some adjuvants contain squalene, a natural compound derived from shark liver oil which is found most abundantly in deep-sea sharks. In recent decades, there has been growing conservation concern associated with the sustainability of many shark fisheries. The need for a potentially massive number of adjuvant-containing SARS-CoV-2 vaccines may increase global demand for shark-derived squalene, with possible consequences for shark conservation, especially of vulnerable and understudied deep-sea species. A shift to non-animal-derived sources of squalene, which are similar in cost and identical in effectiveness, or an emphasis on increasing traceability and sustainability of shark-derived squalene from existing well-managed fisheries, could better support conservation and public health goals.

Keywords: Squalene, COVID-19, SARS-CoV-2, Shark, Liver oil, Vaccines

1. Introduction

Shark populations have historically been exploited for meat, fins, leather, and products derived from their liver oil, including vitamin A and additives to topical cosmetic formulas and lotions (Dent and Clarke, 2015; Lozano-Grande et al., 2018). Some historic shark liver oil fisheries have been associated with intense, short-lived periods of exploitation contributing to stock collapses (Stevens et al., 2000; Kyne and Simpfendorfer, 2007; Anderson and Waheed, 1999; Ali and Sinan, 2014). Sharks, particularly deep-sea species, tend to grow slowly and produce relatively few young, leaving them especially susceptible to overexploitation (Simpfendorfer and Kyne, 2009). Squalene is a natural polyunsaturated hydrocarbon compound ($C_{30}H_{50}$) found in many living organisms that can be refined from shark liver oil. This compound (and its more stable, hydrogenated derivate, squalane) have shown genuine potential to contribute to human health, as an ingredient in vaccines and other pharmaceuticals and dietary supplements (Kim and Karadeniz, 2012).

Many shark species, particularly deep-sea sharks, have relatively large livers (up to 20% of animal weight) which serve as a buoyancy control system and critical energy reserve (Vannuccini 1999; Abel and Grubbs 2020). A significant portion of liver weight is made up of liver oil (10-70%; Nichols et al., 2001), and between 15 and 82% of liver oil is squalene (Deprez et al., 1990; Bakes & Nichols 1995). Although squalene is produced by a range of animals and plants, shark liver oil has historically been a preferred commercial source based on availability and high yields relative to most plant-derived sources.

Squalene can be extracted directly from shark liver oil at high purity (>98%) in approximately 10 hours, using a single distillation process in a vacuum at 200-230º C, a faster process producing greater yields than plant-based alternatives (Camin et al., 2010). Sealed and protected from oxygen and light, squalene has an approximately two-year shelf life, making stable rates of ongoing production important to availability (Camin et al., 2010). Plant-derived squalene can also be refined to a high level of purity for medical applications, and is made up of $C_{30}H_{50}$ molecules chemically identical to those from shark-derived sources. Plant-derived squalene has been shown to perform comparably to shark-derived squalene as an ingredient in vaccine adjuvants (Brito et al. 2011). Accordingly, the FDA is agnostic on the source of squalene and the *Current Good Manufacturing Practice for Finished Pharmaceuticals* only requires that lots of $C_{30}H_{50}$ be "tested for conformity with all appropriate written specifications for purity, strength, and quality" (2019). Chemical vendors listed on the NIH National Library of Medicine for squalene do not differentiate by squalene origin but instead identify the compound by Chemical Abstract Services (CAS) number 7683-64-9, meaning there are no legal or administrative barriers preventing a shift to plant-derived sources of squalene (National Center for Biotechnology Information, 2020).

Shark-derived squalene is a popular ingredient in topical cosmetic formulas and lotions, generating a significant portion of global demand for shark liver oil (Lozano-Grande et al., 2018; Ducos et al., 2015). In recent years, however, consumers and non-profit organizations in the United States and Europe have exerted pressure on the cosmetics industry to transition to plant-derived squalene (Consumers unaware of... 2013; Shark Free). Independent testing by the French non-profit organization Bloom determined most beauty products (>90% of those tested) sold in Europe or the United States no longer contain shark-derived ingredients, although shark-derived squalene remains in common use in beauty products elsewhere (Ducos et al., 2015). More recent studies have demonstrated the presence of shark DNA, including from Threatened and Endangered species, in some US-sold beauty products as well (Cardeñosa et al., 2017; Cardeñosa, 2019).

1.1 Squalene in vaccines

Squalene is used as an adjuvant, a component of a vaccine that enhances efficacy by increasing human immune response and the potency of antigens, while promoting antigen transport into lymph nodes and uptake in the immune cells (Brito and O'Hagan, 2014). The inclusion of adjuvants also reduces the volume of antigen needed per vaccine dose through the process of "antigen sparing," maximizing rates of vaccine production (Tang et al.. 2015; Schmidt et al. 2016). Although the primary global demand for shark liver oil in recent years appears to be for use in cosmetics and lotions (Vannuccini 1999; Lozano-Grande et al., 2018), the role of shark-derived squalene in vaccine production may represent a potential threat to some vulnerable shark populations, given widespread efforts to rapidly develop and disseminate vaccines in response to the COVID-19 pandemic and the patchwork management approach to global shark fishing limits (Ahn et al., 2020; Hodgson, 2020; Davidson et al. 2016).

As an ingredient in adjuvants, squalene has been found to be safe and effective in vaccines for the treatment of viruses including H7N9 and H7N7 (Wu et al., 2014), H1N1 (Vesikari et al., 2012), MERS-CoV (Zhang et al. 2016), and SARS-CoV (Stadler et al., 2005). MF59, an adjuvant containing shark-derived squalene, has been used commercially in influenza vaccines (Schultze et al. 2008; Panatto et al. 2020) and used or tested in previous vaccines for other coronaviruses (Stadler et al., 2005; Zhang et al., 2016).

A few of the potential SARS-CoV-2 vaccines currently in testing include adjuvants MF59 or AS03, which are known to contain shark-derived squalene (COVID-19 Update 2020; GlaxoSmithKline aims... 2020, WHO, 2020). Per dose, MF59 contains 9.75 mg and AS03 contains 10.68 mg of squalene (Jackson et al., 2015). Some potential vaccines are being manufactured in bulk before the completion of large-scale safety and efficacy trials (U.S. to Stockpile... 2020), suggesting that the total number of manufactured doses of various potential vaccines may be far higher than the number ultimately administered. It also remains unknown how frequently revaccination would be necessary if a safe and effective vaccine becomes available (COVID-19 Could Become... 2020; Ellis, 2020; Vaccine companies... 2020), so the scale of possible future demand for squalene as an ingredient in vaccine adjuvants is large but difficult to fully or accurately assess.

Deep-sea sharks are valued in the shark liver oil trade because they offer greater volumes of liver oil than other species. Relatively little is known about population structure, reproduction, and habitat use of many of these species due to the logistical difficulties of conducting research in deep-sea habitats and a generally low research and management priority (e.g., Neiva et al., 2006; Kyne and Simpfendorfer, 2007; Veríssimo et al., 2011). Most elasmobranchs are slow to mature and reproduce, and deep-sea sharks are particularly so, showing population increase rates of less than half those of continental shelf and pelagic shark species relying on shallower habitats (Simpfendorfer and Kyne, 2009). Squaloid sharks (species found in order squaliformes) are a preferred source of liver oil and squalene, and include species which are among the slowest growing and latest maturing sharks known (Musick, 2005). Shark reproductive rates and recovery potential generally decline with increasing depth, and overfished populations of deep-sea shark species may require centuries to recover (Simpfendorfer and Kyne, 2009). Evidence suggests that even low rates of deep-sea shark exploitation (incidental or targeted) is likely to quickly deplete populations (Simpfendorfer and Kyne, 2009). For these reasons, deep-sea sharks have been identified as a conservation priority grouping (Dulvy et al., 2014).

Assessment of the global conservation status of sharks is complicated by poor catch reporting, challenges with species-level identification, and a lack of baseline data. The reported annual catch of sharks likely substantially underestimates actual total catch (Worm et al., 2013; Dulvy et al., 2014). Total catch has been estimated at approximately 100 million animals annually, with an estimate range of 63 to 273 million (Worm et al., 2013). It is particularly difficult to assess rates of capture for species targeted for products like shark liver oil, for which there is relatively little detailed production or trade information available (Fowler et al., 1997; Vannuccini, 1999).

The global trade in shark liver oil is small compared to that in shark fins or meat, and despite the vulnerability of some target species to overfishing has received relatively little media (Shiffman et al., 2020) or scientific attention (Dent and Clarke, 2015). Although there are fisheries in which deep-sea sharks are targeted (see, e.g., Simpfendorfer and Kyne, 2007), liver oil may also be generated opportunistically from incidental catches in fisheries predominantly targeting other fish, or targeting sharks for other products (e.g., meat, fins). In at least some cases, however, the export value of shark liver oil exceeds that of shark meat, and in some locales the available supply of shark liver oil is insufficient to meet processors' demand for raw materials (Dent and Clarke, 2015). A lack of traceability presents a further challenge in assessing the trade in shark liver oil, as the United Nations Food and Agriculture Organization (FAO)'s *Codex Alimentarius* allows for products like squalene to be labelled as originating in the countries in which they were processed even when ingredients (e.g., the liver oil from which the squalene was derived) were produced elsewhere (FAO, 2001).

This study provides a basis for beginning to evaluate the range of potential conservation effects of increasing demand for shark-derived squalene as an ingredient in vaccine adjuvants.

2. Materials and methods

Based on a review of available scientific and management literature, 133 species were identified which are known to be involved in the liver oil trade (Appendix 1), including many that are partially reliant on deep-sea habitat >200 m (n=83) or are found exclusively in the deep-sea (n=21). Additional data on the conservation status and population trends of elasmobranch species, primarily sharks, identified as being involved in the liver oil trade were compiled from their most recent IUCN Red List assessments. Available current trade data on the shark liver oil trade was downloaded from the UN FAO FishStat Database (FAO, 2020). Commercial sources of wholesale quantities of squalene were identified through internet searches and through direct contact with wholesalers to collect pricing, origin, and availability information for both plant- and shark-derived squalene and squalane (its more stable, hydrogenated derivate).

3. Results

Across elasmobranch species identified as being exploited for shark liver oil, 50% had not been assessed by the IUCN in at least ten years, and 30% were considered Data Deficient (Figure 1; an IUCN Shark Specialist Group reassessment of elasmobranch species is currently underway and expected to be completed in 2020 (Dulvy, 2018)). One-third of species identified as part of the shark liver oil trade are classified as threatened (Vulnerable, Endangered, or Critically Endangered) according to IUCN Red List criteria (Figure 2). Population trends for 56% of these species are unknown, and 34% are assessed as showing a decreasing trend (Figure 3).

The most recent FAO data available (2018) showed an increase in reported import and processed production of shark liver oil, with trade volumes reaching 752 tons, the largest reported volume in decades (Figure 4; from 2000-2017, average reported trade volume was under 200 tons annually; Hareide et al., 2007). Despite this increase, the total value of the shark liver oil trade was reported at 553 000 USD in 2018, the lowest value reported since 1987 (mean annual value from 2000-2017, 1 954 000 USD; Hareide et al. 2007; FAO, 2020). Moderate assumptions about oil yield suggest the range of individual animals in the reported global liver oil trade in 2018 falls between 694 848 (large sharks) and 16.35 million (small sharks), with 1.8 million (based on a 20.8 kg median unidentified shark weight; Worm et al. 2013) as the best supported rough estimate (for yield assumptions see Table 1).

Data collected on the price of shark- and plant-derived squalene showed no clear differences, though products listed as both shark- and plant-derived were commonly available in the wholesale market (Table 2). There was significant variability in price across individual sellers (ranging from $20-260/kg for squalene and $10-99.21/kg for squalane). The mean and median price for plant-derived squalene was $40, and the mean price for shark-derived squalene was $45.75 with a median of $48.5/kg (excluding the outlier of $260; including it, the mean price for shark-derived squalene was $76.36, with a median price of $54). The mean price for plant-derived squalane was $53.16/kg (median $48.65/kg), while shark-derived squalane was $45/kg (median $45/kg). These products were identified as being sold from China (67% of products) and the United States (33% of products). Based on these numbers, the estimated potential commercial value of squalene from a single shark ranges from $0.05 (small shark/low yield) to $242.65 (large shark/high yield).

Given that each vaccine dose requires approximately 10mg of squalene, the mean squalene cost-per-vaccine-dose for shark-derived squalene would be $0.0004575 USD, and for plant-derived, $0.0004 USD—a price difference of $0.0000575 per dose.

4. Discussion

These results highlight the extent to which liver oil fisheries could affect shark species of conservation concern, and the potential difficulty of detecting these effects because of a lack of information on the volume of liver-oil-associated catch and the absence of population status information for many deep-sea species. The life history characteristics of deep-sea sharks (Simpfendorfer and Kyne, 2009), insufficient restrictions on exploitation, and declines in availability of shark-derived squalene over time (Sibuyo et al., 2017) suggest that the trade in shark liver oil, while currently small, has potential to disproportinately harm specific vulnerable elasmobranch species and populations.

Estimating potential conservation effects is further complicated by the fact that shark species vary greatly in the percentage of their body weight comprised of the liver (from at least 2.9-20%; Vannucini, 1999; Abel and Grubbs, 2020); in the amount of liver weight made up of oil (ranging from at least 10-70%; Nichols et al., 2001); and in the yield of squalene from extracted liver oil (a range of at least 15-82%; Deprez et al., 1990; Bakes & Nichols 1995). Evidence further suggests animal size, sex, and seasonal and regional factors can also affect yields (Kreuzer and Ahmed, 1978; Nichols et al., 2001). Accordingly, it is impossible to calculate an exact effect of increased vaccine-related demand for shark-derived squalene on shark populations.

We know that fisheries primarily targeting sharks for liver oil exist (e.g., Kyne and Simpfendorfer, 2007), and that, in many cases, multiple products may be marketed from a single shark (e.g., meat, fins, liver oil, cartilage). Data are not available to assess the volume of liver oil generated globally by directed versus incidental fishing. The effect of increased demand for shark-derived squalene is highly dependent on whether it increases targeting of oil-rich deep-sea sharks, or simply drives increased processing and use of the livers of sharks currently taken for other purposes. Thus, conservation effects of vaccine-related demand for squalene could range from minimal (assuming demand is met by more efficient use of individuals already being landed in well-managed fisheries) to catastrophic for individual species (if demand drives the creation of new targeted fisheries for vulnerable deep-sea species in the absence of limits on fishing and trade).

The future availability of shark squalene will likely be constrained by shark population declines and by regulatory efforts to conserve sharks, suggesting the prudence of shifting to more stable and sustainable sources. A vaccine supply chain dependent on shark fisheries is subject to disruption if targeted shark populations collapse or new protections are introduced. Plant-derived alternatives to shark-derived squalene are more environmentally sustainable and readily available. Although in the past shark-derived squalene was reported to be significantly less expensive than plant-derived (Camin et al., 2010), current costs are similar. Non-animal-derived squalene may even be safer for use in some health-related applications because of the reduced risk of contamination with persistent organic pollutants, including polychlorinated biphenyls and organochlorine insecticides, high levels of which have been found in nutritional supplements made from shark liver oil (Rawn et al., 2009).

Despite generally comparable costs between shark- and plant-derived squalene, and potential advantages in long-term availability and contaminant levels, non-animal-derived squalene does not appear to be in current use in vaccine production. Consumer and activist pressure could be effective in encouraging pharmaceutical companies to transition to non-animal-derived squalene in adjuvants, for testing for other medical uses, and in nutraceutical products. Demand-driven increases in production of pharmaceutical grade plant-derived alternatives may also incidentally support reduction or elimination of shark-derived squalene in cosmetic formulations. Increased accountability, including product testing to confirm plant origins and transparency within supply chains, would be vital to a transition away from reliance on shark-derived squalene.

5. Conclusion

The mean difference in cost per dose of a potential SARS-CoV-2 vaccine containing squalene derived from plants instead of shark liver oil is -$0.0000575, based on currently available wholesale price information. While commercially available wholesale squalene may not meet the standard of purity needed for pharmaceutical applications, given these values it would cost $20,125.00 less to generate the 350 million doses needed to vaccinate the U.S. population with plant- rather than shark-derived squalene. Doing the same for the global population of 7 billion would save $402,500.00 over use of shark-derived squalene (without accounting for the effects high demand might have on price or availability).

In addition to similarities in cost, plant-derived sources of squalene have been shown to work comparably as an ingredient in adjuvants, and should not require a new approval process for use because they are chemically identical. Therefore, a shift to non-animal-derived squalene is highly feasible without disrupting efforts to rapidly develop a vaccine. A coordinated commitment by the medical sector to transition to non-animal-derived squalene would support both environmental sustainability and public health goals.

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Table 1

Estimated number of sharks needed to produce two vaccine doses for the global human population under a range of yield assumptions.

Shark weight (kg)	Liver weight	Liver oil weight	Squalene weight	Total sharks*
		Best case		
	20%	70%	82%	
2.3 kg (small shark)	0.46	0.32	0.26	576,049
5.6 kg (deep-sea shark)	1.12	0.78	0.64	236,592
20.8 kg shark (median)	4.16	2.91	2.39	63, 693
46.2 kg (large shark)	9.24	6.47	5.30	28,678
		Moderate case		
	10%	40%	50%	
2.3 kg (small shark)	0.23	0.09	0.05	3,306,522
20.8 kg shark (median)	2.08	0.83	0.42	365,385
46.2 kg (large shark)	4.62	1.85	0.92	164,610
		Worst case		
	3%	10%	15%	
2.3 kg (small shark)	0.069	0.007	0.00104	146,956,522
20.8 kg shark (median)	0.624	0.062	0.00936	16,239,316
46.2 kg (large shark)	1.386	0.139	0.02079	7,316,017

* Based on a maximum demand estimate, assuming use of MF59 adjuvant containing 9.75 mg of squalene per dose to provide 2 vaccines to 7.8 billion people, total squalene demand for vaccines (drawn from existing or new fisheries) would be 152,100 kg.

Table 2

Current listed wholesale prices of shark- and plant-derived squalene and squalane by kg in USD.

Squalene			
Source	*Price/Kg (USD)*	*Sold From*	*Manufacturer*
Shark	$39-47	China	Xi'an Rozen Biotechnology Co., Ltd
Shark	$25	China	Xa Bc-Biotech Co., Ltd
Shark	$54	China	Wuhan Hengheda Pharm Co., Ltd
Shark	$260	China	Haihang Industry Co., Ltd
Shark	$35-80	China	Xi'an Sheerherb Biological Technology
Shark	$20-60	China	Shandong Zesheng Chemical Co., Ltd
Shark	$55	China	Shaanxi Phoenix Tree Biotech Co., Ltd
Olive Oil	$20-60	China	Suzhou Manson Biotech Co., Ltd
Soybeans	$20-60	China	Suzhou Manson Biotech Co., Ltd
Squalane			
Source	*Price/Kg (USD)*	*Sold From*	*Manufacturer*
Shark	~$40	USA	Jedwards International INC.
Shark	$50	China	Xa Bc-Biotech Co, Ltd
Olive Oil	$44.89	USA	Cocojojo Beauty
Olive Oil	$63.99	USA	Organic Gold
Olive Oil	$10-20	China	Shandong Zhonglan Chemical Co., Ltd
Olive Oil	$40-60	China	Xi'an Geekee Biotech Co., Ltd
Olive Oil	~$51.75	USA	Jedwards International INC.
Olive Oil	~$47.30	USA (Origin Italy, Spain)	Blossom Bulk Ingredients
Neossance (Sugarcane)	$99.21	USA	HBNO

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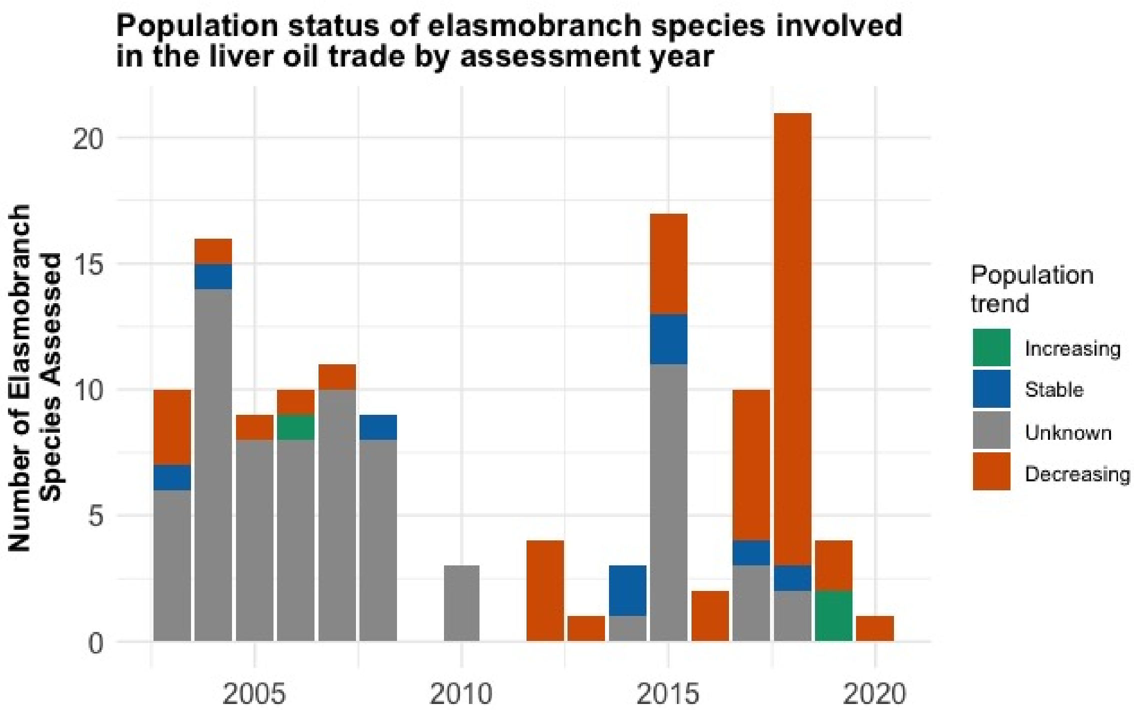

Figure 1. Most recent IUCN Red List assessments for assessed elasmobranch species (n=131) reported in the liver oil trade. The earliest assessment of a species identified as traded for liver oil took place in 2003.

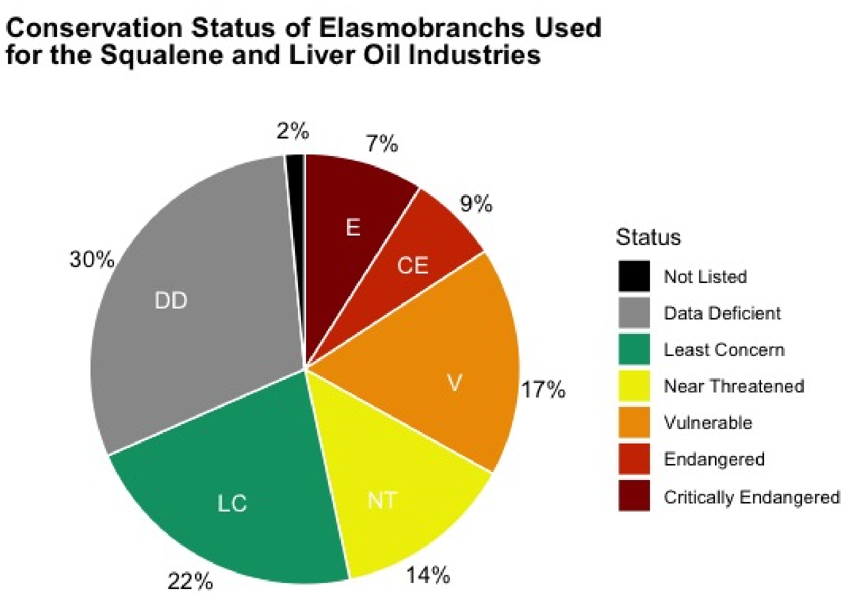

Figure 2. IUCN Red List conservation status of elasmobranch species reported in the liver oil trade.

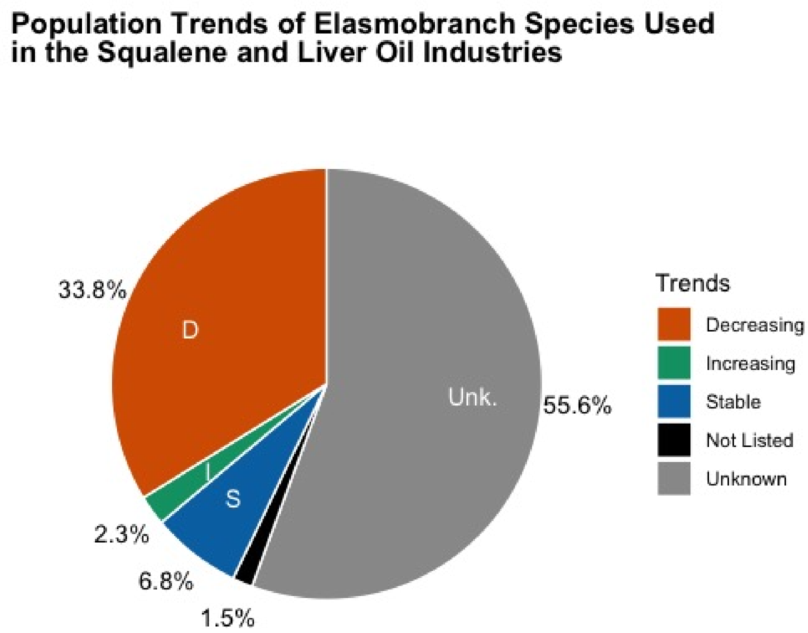

Figure 3. IUCN Red List population trends of all elasmobranch species reported in the liver oil trade.

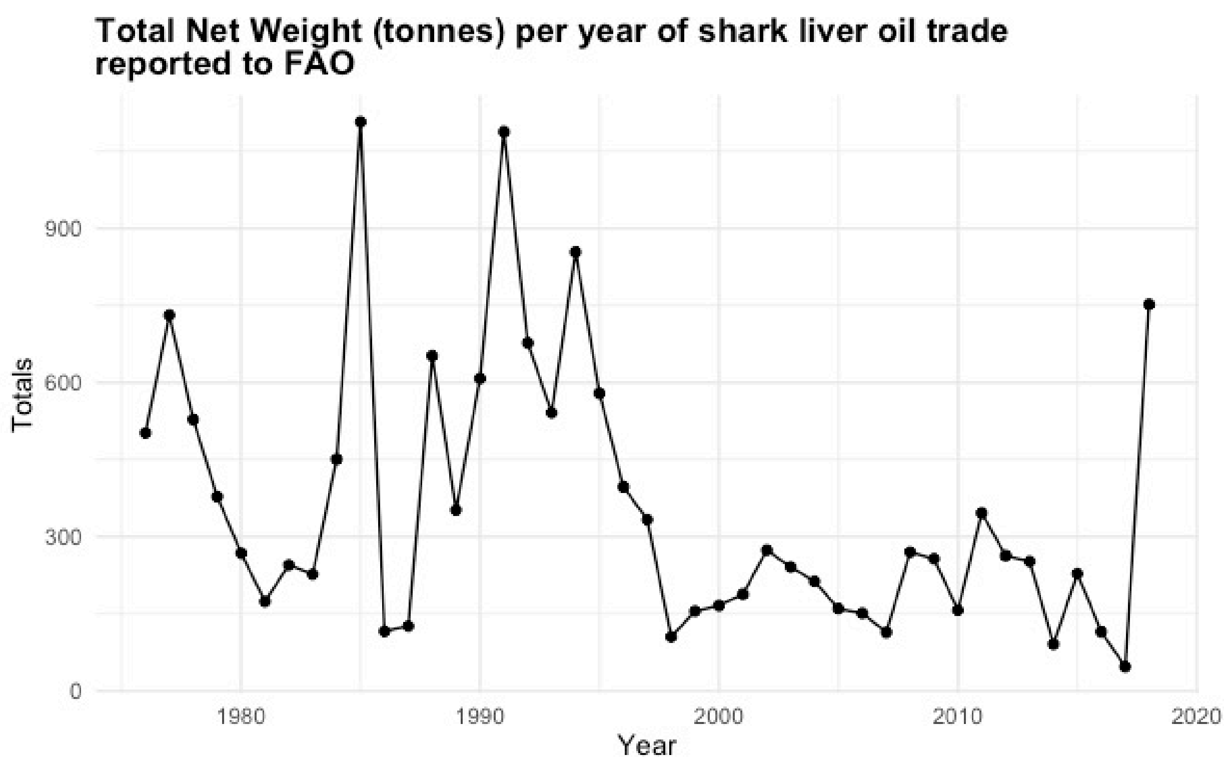

Figure 4. The total reported net weight (tonnes) of annual trade in shark liver oil reported to FAO. In 2018, two countries reported trade: imports of 33 tonnes (Republic of Korea) and processed production of 719 tonnes (Senegal).

Appendix A: Elasmobranchs reported to be used in the liver oil and squalene trades, including IUCN conservation status and population trend assessment information.

Table A.1

Scientific Name	**Family Name**	**Common Name**	**Source**	**IUCN Conservation Status**	**IUCN Assessed Population Trend**	**Year Last Assessed**
Alopias pelagicus	Alopiidae	Pelagic Thresher	Vannuccini 1999	EN	Decreasing	2018
Alopias superciliosus	Alopiidae	Bigeye Thresher	Vannuccini 1999	VU	Decreasing	2018
Alopias vulpinas	Alopiidae	Common Thresher	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
Anoxypristis cuspidata	Pristidae	Knifetooth Sawfish/Narrow Sawfish	Fowler et al., 1997	EN	Decreasing	2012
Atelomycterus baliensis	Scyliorhinidae	Bali Catshark	Fowler et al., 1997	VU	Unknown	2008
Atelomycterus fasciatus	Scyliorhinidae	Banded Catshark	Fowler et al., 1997	LC	Unknown	2015
Atelomycterus macleayi	Scyliorhinidae	Australian Marbled Catshark	Fowler et al., 1997	LC	Unknown	2015
Atelomycterus marmoratus	Scyliorhinidae	Coral Catshark	Fowler et al., 1997	NT	Unknown	2003
Atelomycterus marnkalha	Scyliorhinidae	Eastern Banded Catshark	Fowler et al., 1997	DD	Unknown	2015
Aulohalaelurus kanakorum	Scyliorhinidae	New Caledonia Catshark	Fowler et al., 1997	DD	Unknown	2017
Aulohalaelurus labiosus	Scyliorhinidae	Black Spotted Catshark	Fowler et al., 1997	LC	Unknown	2015
Carcharhinus albimarginatus	Carcharhinidae	Silvertip Shark	Vannuccini 1999	VU	Decreasing	2015
Carcharhinus altimus	Carcharhinidae	Bignose Shark	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2008
Carcharhinus amblyrhynchos	Carcharhinidae	Grey Reef Shark	Vannuccini 1999	NT	Unknown	2005
Carcharhinus brevipinna	Carcharhinidae	Spinner Shark	Fowler et al., 1997;	NT	Unknown	2005

			Vannuccini 1999			
Carcharhinus falciformis	Carcharhinidae	Silky Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
Carcharhinus leucas	Carcharhinidae	Bull Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
Carcharhinus limbatus	Carcharhinidae	Blacktip Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
Carcharhinus longimanus	Carcharhinidae	Oceanic Whitetip Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2018
Carcharhinus melanopterus	Carcharhinidae	Blacktip Reef Shark	Fowler et al., 1997; Vannuccini 1999	NT	Decreasing	2005
Carcharhinus obscurus	Carcharhinidae	Dusky Shark	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
Carcharhinus plumbeus	Carcharhinidae	Sandbar Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2007
Carcharias taurus	Odontaspididae	Sand Tiger Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2016
Carcharodon carcharias	Lamnidae	White Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
Centrophorus acus	Centrophoridae	Needle Dogfish	Fowler et al., 1997; Vannuccini 1999	Not Listed	Not Listed	Not Listed
Centrophorus lusitanicus	Centrophoridae	Lowfin Gulper Shark	Fowler et al., 1997; Vannuccini 1999	VU	Unknown	2008
Centrophorus niaukang	Centrophoridae	Taiwan Gulper Shark	Fowler et al., 1997	Not Listed	Not Listed	Not Listed

Centrophorus squamosus	Centrophoridae	Leafscale Gulper Shark	Fowler et al., 1997;; Vannuccini 1999	VU	Decreasing	2003
Centroselachus crepidater	Somniosidae	Longnose Velvet Dogfish	Fowler et al., 1997; Vannuccini 1999	LC	Unknown	2003
Cephaloscyllium albipinnum	Scyliorhinidae	Whitefin Swellshark	Fowler et al., 1997	CR	Decreasing	2018
Cephaloscyllium cooki	Scyliorhinidae	Cook's Swellshark	Fowler et al., 1997	DD	Unknown	2015
Cephaloscyllium fasciatum	Scyliorhinidae	Reticulated Swellshark	Fowler et al., 1997	DD	Unknown	2010
Cephaloscyllium hiscosellum	Scyliorhinidae	Reticulate Swellshark	Fowler et al., 1997	LC	Unknown	2015
Cephaloscyllium isabellum	Scyliorhinidae	Carpet Shark	Fowler et al., 1997	LC	Stable	2017
Cephaloscyllium laticeps	Scyliorhinidae	Australian Swellshark	Fowler et al., 1997	LC	Stable	2015
Cephaloscyllium maculatum	Scyliorhinidae	Spotted Swellshark	Fowler et al., 1997	DD	Unknown	2010
Cephaloscyllium pardelotum	Scyliorhinidae	Leopard-spotted Swellshark	Fowler et al., 1997	DD	Unknown	2010
Cephaloscyllium sarawakensis	Scyliorhinidae	Sarawak Pygmy Swell Shark	Fowler et al., 1997	DD	Unknown	2008
Cephaloscyllium signourum	Scyliorhinidae	Flagtail Swellshark	Fowler et al., 1997	DD	Unknown	2015
Cephaloscyllium silasi	Scyliorhinidae	Indian Swellshark	Fowler et al., 1997	DD	Unknown	2008
Cephaloscyllium speccum	Scyliorhinidae	Speckled Swellshark	Fowler et al., 1997	DD	Unknown	2015
Cephaloscyllium sufflans	Scyliorhinidae	Balloon Shark	Fowler et al., 1997	NT	Decreasing	2019
Cephaloscyllium umbratile	Scyliorhinidae	Japanese Swellshark	Fowler et al., 1997	DD	Unknown	2007
Cephaloscyllium variegatum	Scyliorhinidae	Saddled Swellshark	Fowler et al., 1997	NT	Decreasing	2018
Cephaloscyllium ventriosum	Scyliorhinidae	Swell Shark	Fowler et al., 1997	LC	Unknown	2015

Cephaloscyllium zebrum	Scyliorhinidae	Narrowbar Swellshark	Fowler et al., 1997	DD	Unknown	2015
Cetorhinus maximus	Cetorhinidae	Basking Shark	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
Cirrhigaleus asper	Squalidae	Roughskin Shark/Roughskin Spurdog	Fowler et al., 1997; Vannuccini 1999	VU	Unknown	2017
Cirrhigaleus barbifer	Squalidae	Mandarin Dogfish	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2007
Dalatias licha	Dalatiidae	Kitefin Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
Dasyatis pastinaca	Dasyatidae	Common Stingray	Vannuccini 1999	DD	Unknown	2003
Deania calcea	Centrophoridae	Birdbeak Dogfish	Fowler et al., 1997; Vannuccini 1999	LC	Unknown	2003
Echinorhinus brucus	Echinorhinidae	Bramble Shark	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2003
Eusphyra blochii	Sphyrnidae	Winghead Shark	Fowler et al., 1997	EN	Decreasing	2015
Galeocerdo cuvier	Carcharhinidae	Tiger Shark	Fowler et al., 1997; Vannuccini 1999	NT	Decreasing	2018
Galeorhinus galeus	Triakidae	Tope Shark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2020
Galeus antillensis	Pentanchidae	Antilles Catshark	Vannuccini 1999	DD	Unknown	2004
Galeus arae	Pentanchidae	Roughtail Catshark	Vannuccini 1999	LC	Unknown	2004
Galeus atlanticus	Pentanchidae	Atlantic Sawtail Catshark	Vannuccini 1999	NT	Unknown	2007
Galeus cadenati	Pentanchidae	Longfin Sawtail Catshark	Vannuccini 1999	DD	Unknown	2004

Galeus eastmani	Pentanchidae	Gecko Catshark	Vannuccini 1999	LC	Unknown	2007
Galeus gracilis	Pentanchidae	Slender Sawtail Shark	Vannuccini 1999	DD	Unknown	2015
Galeus longirostris	Pentanchidae	Longnose Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
Galeus melastomus	Pentanchidae	Blackmouth Catshark	Vannuccini 1999	LC	Stable	2003
Galeus mincaronei	Pentanchidae	Southern Sawtail Catshark	Vannuccini 1999	VU	Decreasing	2004
Galeus murinus	Pentanchidae	Mouse Catshark	Vannuccini 1999	LC	Stable	2014
Galeus nipponensis	Pentanchidae	Broadfin Sawtail Catshark	Vannuccini 1999	DD	Unknown	2008
Galeus piperatus	Pentanchidae	Peppered Catshark	Vannuccini 1999	LC	Unknown	2006
Galeus polli	Pentanchidae	Galeus polli	Vannuccini 1999	LC	Stable	2004
Galeus priapus	Pentanchidae	Phallic Catshark	Vannuccini 1999	LC	Unknown	2017
Galeus sauteri	Pentanchidae	Blacktip Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
Galeus shcultzi	Pentanchidae	Dwarf Sawtail Catshark	Vannuccini 1999	DD	Unknown	2007
Galeus springeri	Pentanchidae	Galeus springeri	Vannuccini 1999	DD	Unknown	2004
Glaucostegus typus	Glaucostegidae	Giant Guitarfish	Vannuccini 1999	CR	Decreasing	2018
Hemipristis elongata	Hemigaleidae	Snaggletooth Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2015
Hexanchus griseus	Hexanchidae	Bluntnose Sixgill Shark	Fowler et al., 1997; Vannuccini 1999	NT	Unknown	2005
Isurus oxyrinchus	Lamnidae	Shortfin Mako	Fowler et al., 1997; Vannuccini 1999	EN	Decreasing	2018
Isurus paucus	Lamnidae	Longfin Mako	Fowler et al., 1997;	EN	Decreasing	2018

			Vannuccini 1999			
Lamna ditropis	Lamnidae	Salmon Shark	Fowler et al., 1997; Vannuccini 1999	LC	Stable	2018
Lamna nasus	Lamnidae	Porbeagle Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2018
Mestelus manazo	Triakidae	Starspotted Smoothhound	Fowler et al., 1997	DD	Unknown	2007
Mustelus californicus	Triakidae	Gray Smooth Hound	Vannuccini 1999	LC	Unknown	2014
Mustelus griseus	Triakidae	Spotless Smooth Hound	Vannuccini 1999	DD	Unknown	2007
Nebrius ferrugineus	Ginglymostomatidae	Tawny Nurse Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2003
Negaprion acutidens	Carcharhinidae	Sharptooth Lemon Shark/ Sicklefin Lemon Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2003
Odontaspis ferox	Odontaspididae	Smalltooth Sand Tiger Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2015
Odontaspis noronhai	Odontaspididae	Bigeye Sand Tiger Shark	Fowler et al., 1997	LC	Unknown	2018
Poroderma africanum	Scyliorhinidae	Pyjama Shark	Fowler et al., 1997	LC	Increasing	2019
Poroderma pantherinum	Scyliorhinidae	Leopard Catshark	Fowler et al., 1997	LC	Increasing	2019
Prionace glauca	Carcharhinidae	Blue Shark	Vannuccini 1999	NT	Decreasing	2018
Pristiophorus nudipinnis	Pristiophoridae	Southern Sawshark	Vannuccini 1999	LC	Stable	2015
Pristis clavata	Pristidae	Dwarf Sawfish	Fowler et al., 1997	EN	Decreasing	2012
Pristis pectinata	Pristidae	Smalltooth Sawfish/Wide Sawfish	Fowler et al., 1997	CR	Decreasing	2012

Pristis pristis	Pristidae	Largetooth Sawfish	Fowler et al., 1997	CR	Decreasing	2013
Pristis zijsron	Pristidae	Longcomb Sawfish/Green Sawfish	Fowler et al., 1997	CR	Decreasing	2012
Rhincodon typus	Rhincodontidae	Whale Shark	Vannuccini 1999	EN	Decreasing	2016
Schroederichthys bivius	Scyliorhinidae	Narrowmouth Catshark	Fowler et al., 1997	DD	Unknown	2005
Schroederichthys chilensis	Scyliorhinidae	Chilean Catshark	Fowler et al., 1997	DD	Unknown	2004
Schroederichthys maculatus	Scyliorhinidae	Narrowtail Catshark	Fowler et al., 1997	LC	Unknown	2004
Schroederichthys saurisqualus	Scyliorhinidae	Lizard Catshark	Fowler et al., 1997	VU	Unknown	2004
Schroederichthys tenuis	Scyliorhinidae	Slender Catshark	Fowler et al., 1997	DD	Unknown	2004
Scyliorhinus besnardi	Scyliorhinidae	Scyliorhinus besnardi	Fowler et al., 1997	DD	Unknown	2004
Scyliorhinus boa	Scyliorhinidae	Boa Catshark	Fowler et al., 1997	LC	Unknown	2004
Scyliorhinus canicula	Scyliorhinidae	Small Spotted Cat Shark	Fowler et al., 1997	LC	Stable	2008
Scyliorhinus capensis	Scyliorhinidae	Yellow Spotted Catshark	Fowler et al., 1997	NT	Decreasing	2019
Scyliorhinus cervigoni	Scyliorhinidae	Scyliorhinus cervigoni	Fowler et al., 1997	DD	Unknown	2006
Scyliorhinus comoroensis	Scyliorhinidae	Comoro Catshark	Fowler et al., 1997	DD	Unknown	2018
Scyliorhinus garmani	Scyliorhinidae	Brownspotted Catshark	Fowler et al., 1997	DD	Unknown	2007
Scyliorhinus haecklii	Scyliorhinidae	Scyliorhinus haecklii	Fowler et al., 1997	DD	Unknown	2004
Scyliorhinus hesperius	Scyliorhinidae	Scyliorhinus hesperius	Fowler et al., 1997	DD	Unknown	2004
Scyliorhinus meadi	Scyliorhinidae	Scyliorhinus meadi	Fowler et al., 1997	DD	Unknown	2006
Scyliorhinus retifer	Scyliorhinidae	Scyliorhinus retifer	Fowler et al., 1997	LC	Increasing	2006
Scyliorhinus stellaris	Scyliorhinidae	Nursehound	Fowler et al., 1997	NT	Unknown	2006

Scyliorhinus tokubee	Scyliorhinidae	Izu Catshark	Fowler et al., 1997	DD	Unknown	2008
Scyliorhinus torazame	Scyliorhinidae	Cloudy Catshark	Fowler et al., 1997	LC	Unknown	2008
Scyliorhinus torrei	Scyliorhinidae	Dwarf Catshark	Fowler et al., 1997	LC	Unknown	2004
Scymnodon plunketi	Somniosidae	Plunket's Shark	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2017
Somniosus microcephalus	Somniosidae	Greenland Shark	Vannuccini 1999	NT	Unknown	2006
Sphyrna corona	Sphyrnidae	Scalloped Bonnethead	Vannuccini 1999	NT	Unknown	2004
Sphyrna lewini	Sphyrnidae	Scalloped Hammerhead	Vannuccini 1999	CR	Decreasing	2018
Sphyrna media	Sphyrnidae	Scoophead Shark	Vannuccini 1999	DD	Unknown	2006
Sphyrna mokarran	Sphyrnidae	Great Hammerhead	Vannuccini 1999	CR	Decreasing	2018
Sphyrna tiburo	Sphyrnidae	Bonnethead Shark	Vannuccini 1999	LC	Stable	2014
Sphyrna tudes	Sphyrnidae	Smalleye Hammerhead	Vannuccini 1999	VU	Decreasing	2006
Sphyrna zygaena	Sphyrnidae	Smooth Hammerhead	Fowler et al., 1997	VU	Decreasing	2018
Squalus acanthias	Squalidae	Piked Dogfish/Spiny Dogfish	Fowler et al., 1997; Vannuccini 1999	VU	Decreasing	2016
Squalus cubensis	Squalidae	Cuban Dogfish	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2006
Squalus mitsukurii	Squalidae	Shortspine spurdog	Fowler et al., 1997; Vannuccini 1999	DD	Unknown	2007
Squatina aculeata	Squatinidae	Sawback Angelshark	Fowler et al., 1997; Vannuccini 1999	CR	Decreasing	2017
Squatina oculata	Squatinidae	Smoothback Angelshark	Fowler et al., 1997	CR	Decreasing	2017

Squatina squatina	Squatinidae	Angelshark	Fowler et al., 1997	CR	Decreasing	2017
Triaenodon obesus	Carcharhinidae	Whitetip Reef Shark	Vannuccini 1999	NT	Unknown	2005